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DESCRIPTION

OVERSTEER STEERING ASSISTANCE CONTROLLER

The present invention relates to a vehicle dynamic control system of the type that employs an electrically assisted steering system (EAS) and has means to counter the effects of vehicle oversteer.

EAS systems are well known in the art. Electric assist steering systems that use, for example, a rack and pinion gear set to couple the steering column to the steered axle provide power assist by using an electric motor to either apply rotary force to a steering shaft connected to a pinion gear, or apply linear force to a steering member having rack teeth thereon. The electric motor in such systems is typically controlled in response to (a) driver's applied torque to the steering wheel, and (b) sensed vehicle speed.

Other known electric assist steering systems include electro-hydraulic systems in which the power assist is provided by hydraulic means under at least partial control of an electronic control system.

Oversteer is the tendency of a vehicle to steer into a sharper turn than the driver intends and where there can be a thrusting of the rear of the vehicle outwardly of the bend, causing the rear of the car to start to slide due to the rear tyres losing lateral traction. This type of event is considered the most dangerous condition for a vehicle to be in and frequently results in the vehicle spinning out of control. Vehicle Stability Control (VSC) systems have been developed that prevent this by selectively applying the brakes at individual wheels. Such systems

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are expensive and therefore only suited for fitment to higher end cars, whereas power steering systems are now fitted to almost all types of vehicle. Therefore an oversteer assistance system that could use the steering system would not only assist VSC in stabilising the vehicle, but would also be of more widespread application.

It is therefore an object of the present invention to use the power steering system to aid the driver in stabilizing the vehicle during an oversteer condition.

According to the present invention a steering assistance controller is provided for the generation of a compensating torque which assists the driver in overcoming the tendency of a vehicle to oversteer by encouraging the driver to steer the vehicle back to a non-oversteering condition through the application of said compensating torque which is based at least in part upon vehicle state information. Preferably, the vehicle state information is comprised of one or more of vehicle yaw rate, lateral acceleration, vehicle side slip, longitudinal velocity, lateral velocity, steering wheel angle, steering wheel velocity, driver applied steering torque and yaw acceleration.

An algorithm is provided that uses measurements of the vehicle dynamic state to determine a steer correction suitable to stabilise a vehicle in oversteer, this steer correction being applied to the vehicle via the normal power assisted steering system.

Preferably, the steering assistance controller derives an estimation of the tendency of the vehicle to oversteer based upon measurements the measured or derived vehicle yaw rate, and/or, lateral acceleration, and/or steering wheel angle,

and/or lateral acceleration and/or slip angle.

Such data is readily available from known ABS systems of the VSC (Vehicle Stability Control) type where stability of the vehicle is further enhanced through selective application of the vehicle braking system.

Preferably, the steering assistance controller is adapted to derive the estimation of the tendency of the vehicle to oversteer based upon estimates of vehicle yaw rate which are compared with measurements of actual vehicle yaw rate to provide a yaw rate error which is used as a measure of oversteer present on the vehicle.

In one advantageous embodiment, the steering controller includes a closed loop observer having yaw rate feedback which is arranged such that, when the vehicle starts to oversteer, a non-linear region is entered and the previously existing linear estimate diverges from the feedback signal whereby the magnitude of the vehicle yaw rate is greater than the magnitude of the estimated yaw rate, thereby producing a negative yaw rate error which is used to generate a proportional signal indicative of the magnitude of the oversteer.

Preferably, the steering assistance controller is adapted to derive the estimation of the tendency of the vehicle to oversteer using measurements from lateral acceleration sensors placed in the front and rear axles of the vehicle.

In one embodiment, signals corresponding to the lateral accelerations measured at the front and rear axles are passed through a phase detection device, the phase difference being used for calculation of the magnitude of oversteer..

Conveniently, the state of the vehicle is formed from $\lambda = \Theta_{th}\Theta$

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where λ is the vehicle state, θ_{th} is a phase lag threshold and θ is the phase difference between the two lateral acceleration sensors, positive values of λ indicating that the vehicle is in oversteer and λ is proportional to the amount of oversteer present.

In other embodiments, the steering controller can be adapted to derive an estimation of the tendency of the vehicle to oversteer based upon two vehicle models representing an understeering and an oversteering vehicle which are compared to provide an indication of vehicle oversteer magnitude.

Advantageously, the difference in dynamics between the two models is achieved by altering the tyre cornering stiffnesses in the models, reducing the front tyre stiffness in one model creating an understeering vehicle and reducing the rear tyre stiffness in the other model creating an oversteering vehicle, and comprising comparators which calculate the error between the measured lateral acceleration and estimated lateral acceleration at that axle for each model, based on:

$$\lambda_f = \left| A_{fm} - A_{fu} \right| - \left| A_{fm} - A_{fo} \right|$$

where

A_{fu} = Front Axle Lat Acc Estimated from Understeer Model

A_{ru} = Rear Axle Lat Acc Estimated from Understeer Model

A_{fo} = Front Axle Lat Acc Estimated from Oversteer Model

A_{ro} = Rear Axle Lat Acc Estimated from Oversteer Model

A_{fm} = Front Axle Lat Acc Measured from Sensor

A_{rm} = Rear Axle Lat Acc Measured from Sensor

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this giving two values for the vehicle state which are added together to produce an overall vehicle stability factor λ, positive values of which are indicative of vehicle oversteer.

In still further embodiments, the steering assistance controller is adapted to derive an estimation of the tendency of the vehicle to oversteer based upon a percentage of the VSC threshold at which brake intervention for oversteer occurs.

Preferably, the steering controller includes a steering controller which generates an input to the vehicle steering system based on the amount of estimated vehicle oversteer.

Advantageously, the steering assistance controller is adapted to control the steering by applying a pulse input or "nudge" to indicate to the driver the correct time and direction to apply steering control.

In one embodiment, a signal is arranged to be generated in a nudge controller if the vehicle yaw rate error is detected to be greater than a predetermined threshold, this signal being used to trigger a latch, the output of which sets an integrator ramping, said signal also being used to generate a torque demand signal which is fed to the steering system to initiate the start of the "nudge", saturation of the integrator resetting the latch and ending the "nudge".

Advantageously, the steering assistance controller is adapted to control the steering by means of closed loop control of the steering wheel velocity.

In one embodiment, a PD controller is implemented on the vehicle yaw rate error to generate a steering rate demand which is compared with a scaled version of the steering wheel velocity to produce an error signal, a second PD

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controller then providing a signal which attempts to move the steering wheel with a desired direction and velocity to correct the oversteer.

The steering assistance control can also include an activation control which is adapted to fade the controller in when it has decided that the oversteer has exceeded limits and to fade the controller out once the oversteer has returned to an acceptable value.

Preferably, the activation control comprises activation logic which is adapted to control the point at which the controller starts, deactivation logic which detects conditions for deactivation of the controller, and a fade control which fades the inputs and outputs from the controller in and out as the controller is switched on and off.

Advantageously, the activation logic comprises a threshold oversteer value and a latch arranged such that when the oversteer signal exceeds the threshold, the latch is set and remains set until a deactivation flag triggers a reset.

The fade control can comprise an integrator which, upon detection of an activation flag being high, is arranged to ramp up to allow the torque generated by the steering controller to be gradually added to the steering system but which, on detection of the activation flag becoming low, ramps down to gradually remove the effect of the controller torque from the steering system.

The invention is described further hereinafter, by way of example only, with reference to the accompanying drawings, in which:-

Fig. 1 is an overall system block diagram of one embodiment of an oversteer steering assistance controller in accordance with this invention;

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Fig. 2 illustrates how yaw rate is estimated;

Fig. 3 illustrates oversteer estimation by Phase Detection;

Fig. 4 illustrates oversteer estimation by Model Comparison;

Fig. 5 is a block diagram of a "nudge" controller;

Fig. 6 is a block diagram of a steering wheel rate controller;

Fig. 7 is an overall block diagram of activation logic;

Fig. 8 is a block diagram of the activation logic;

Fig. 9 is a block diagram showing deactivation logic;

Fig.10 is a block diagram of a fade control arrangement;

Fig. 11 shows an alternative steering controller; and

Fig. 12 shows a means of establishing slip angle.

Referring first to Fig. 1, the oversteer steering assistance controller

comprises three sections, namely:

Oversteer Estimation. The Oversteer Estimation 10 attempts to estimate

the amount of oversteer that the vehicle is currently experiencing.

Steering controller. Based on the amount of oversteer, the Steering

Controller 14 generates an input to the steering system to assist the driver in

correction.

Activation Control. The Activation Control/Logic 12 fades the controller

in when it has determined that the oversteer has exceeded limits. It also controls

the fading out of the controller once the oversteer and other vehicle parameters

have returned to acceptable values.

Oversteer Estimation

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(a) Integrated Estimation - VSC ICC Oversteer/Understeer Signal

The Integrated Chassis System VSC code produces a measure of the vehicle understeer or oversteer. -100% is the point where brake intervention occurs to counter a severe understeer. 0% is the vehicle operating without any understeer or oversteer. +100% indicates the initiation of brake intervention to prevent a severe oversteer.

For the purposes of oversteer control, only positive values are taken, all negative values are ignored. There is no requirement for a limiter as the signal is inherently limited to 100%.

(b) Dynamic Estimation

The dynamic estimator is a closed loop observer 16 with yaw rate feedback, estimating yaw rate, as illustrated in Fig. 2. When the vehicle starts to oversteer, a non-linear region is entered and the linear estimate diverges from the feedback signal. In this condition, the magnitude of the vehicle yaw rate is greater than the magnitude of the estimated yaw rate, producing a negative yaw rate error. A logic block 18 detects the negative yaw rate error and outputs a signal that is proportional to the magnitude of the yaw rate error. This signal is a measure of the amount of oversteer present on the vehicle.

(c) Dynamic Estimation with Lateral Acceleration

It is possible to estimate the amount of oversteer on the vehicle using two lateral acceleration sensors, one placed on the front axle and one of the rear axle. There are a number of methods of achieving this, as explained hereinafter.

(d) Oversteer Estimation by Phase Detection

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As shown in Fig. 3. The lateral accelerations measured at the front and rear

axles are passed through a phase detection device 20.

The phase detection device 20 uses a cross correlation to determine the

time delay between the two signals. From this, the phase difference can be

determined.

Once the phase between the front and rear lateral acceleration signals has

been determined, the state of the vehicle can be found from:

$$\lambda = \Theta_{th} - \Theta$$

where λ is the vehicle state, Θ_{th} is a phase lag threshold and Θ is the phase

difference between the two lateral acceleration sensors. In normal driving

conditions, the rear axle will tend to lag the front axle and this phase difference is

set as the value of Θ_{th}. Therefore, in normal driving λ is around 0. As the vehicle

starts to oversteer, the lateral acceleration of the rear axle catches up with the front

axle, causing Θ to fall. In high values of oversteer, Θ can change sign, i.e. the

lateral acceleration at the rear axle now leads that at the front axle. It can

therefore be seen that positive values of λ indicate that the vehicle is in oversteer

and λ is proportional to the amount of oversteer present on the vehicle.

(e) Oversteer Estimation by Model Comparison

As illustrated in Fig. 4, two vehicle models 22, 24, are created,

representing an understeering and oversteering vehicle. The difference in

dynamics between the models 22, 24 is achieved by altering the tyre cornering

stiffness. Reduction of the front tyre stiffness by around a third creates an

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understeering vehicle, while a similar reduction for the rear creates oversteer.

Referring to Fig. 4, the following nomenclature applies:

A_{fu} = Front Axle Lat Acc Estimated from Understeer Model

A_{ru} = Rear Axle Lat Acc Estimated from Understeer Model

A_{fo} = Front Axle Lat Acc Estimated from Oversteer Model

A_{ro} = Rear Axle Lat Acc Estimated from Oversteer Model

A_{fm} = Front Axle Lat Acc Measured from Sensor

A_{rm} = Rear Axle Lat Acc Measured from Sensor

Comparators 26 and 28 first calculate the error between the measured

lateral acceleration and the estimated lateral acceleration at that axle for each

model:

$$\lambda_f = \left| A_{fm} - A_{fu} \right| - \left| A_{fm} - A_{fo} \right|$$

This gives two values for the vehicle state which are added together to

produce an overall vehicle stability factor, λ. For normal straight line driving λ

should tend to 0. As the vehicle generates more understeer then λ becomes

negative. If the vehicle moves into oversteer, then λ should become positive.

Therefore λ is proportional to the dynamic state of the vehicle.

Steering Controller

There are two possible methods of controlling the steering. The first is just

to apply a pulse input, or a nudge, to indicate to the driver the correct time and

direction to apply steering control. The alternative is more comprehensive and

applies closed loop control of the steering wheel velocity.

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(a) Nudge Control

The nudge control uses a PD control on yaw rate with an additional output block 30 as illustrated in Fig. 5. The additional block 30 does nothing until the torque demand from the yaw rate controller reaches a threshold. Then a torque pulse is generated that is intended to nudge the driver into moving the vehicle in the correct direction.

A '1' is generated in the nudge controller 30 if the yaw rate error is greater than a threshold. This is used to trigger a set/reset latch 32, the output of which sets an integrator 34 ramping. At the same time, the '1' out of the SR latch 32 is scaled by a gain 36 and generates a torque, the start of the nudge. This is given the same sign as the torque error and fed to the steering system. In this implementation, the gain is constant and therefore the torque applied to the steering system is independent of the severity of the oversteer condition. It is possible to make this gain a map, with the index being either the oversteer value, yaw rate, or yaw acceleration. This would then change the amplitude of the steering nudge dependent on manoeuvre. When the integrator 34 saturates, a flag is generated which causes the SR latch 32 to reset. When this occurs, the torque output to the steering system falls to zero ending the nudge, and the integrator 34 is reset. By varying the saturation value on the integrator 34, the duration of the applied steering nudge can be controlled.

(b) Steering Wheel Rate Control

The aim of the closed loop steering wheel velocity controller, shown in Fig. 6 is to attempt to match the yaw rate of the front road wheels with the yaw

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rate of the vehicle but the opposite sign. This has the effect of causing the vehicle to seemingly pivot about the front wheels.

The controller assumes that the driver is attempting to reduce the yaw rate of the vehicle to zero and assists the driver in achieving this. However, if the system was combined with a video sensor capable of providing a heading angle demand, then this input could reflect a yaw rate demand required to keep the vehicle heading in the correct direction. In the first element 38, a PD controller is implemented on the yaw rate error signal to generate a steering rate demand. This is compared with a scaled version of the handwheel velocity to produce an error signal. A final PD controller 40 then attempts to move the handwheel with the desired direction and velocity. A limit 42 prevents the controller applying torques that may lead to excessive handwheel velocities.

As an alternative to the steering wheel rate controller of Fig. 6, there can be used the steering controller of Fig. 11 which has as one of its inputs a value corresponding to the vehicle side slip. Side slip can be established, by way of example, using the arrangement of Fig. 12. As shown in Fig. 12, side slip cangle can be generated from a combination of steer angle and yaw rate scaled for vehicle longitudinal velocity. The output of this combination when processed according to the bicycle model, produces vehicle lateral velocity. Further comparison of this value with vehicle longitudinal velocity produces a side slip angle which can then be fed into the vehicle controller to produce a steering demand as shown in Fig.11.

The overall structure of the arrangement of Fig. 11 is substantially the same as for the steering rate controller with side slip as an input. The vehicle

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controller simply uses the inputs to determine a suitable output which is preferably either steering wheel angle/position. The Vehicle Controller itself can be one of a P, P+D, P+1+D, pole placement, frequency response commentator etc type controller.

By way of a specific solution, the simplest option is a gain on the controller inputs, each provided to scale the output based on the bicycle or other vehicle model. The gain outputs are then added together to form the steering demand signal which can be represented by steering wheel position demand or steering wheel velocity demand.

Similarly steering control function provides an output of steering torque based upon the inputs of steering wheel position and/or velocity when compared to the steering demand.

Activation Control

The activation control illustrated in Fig. 7 comprises three separate sections:

(i) Activation Logic 44 which controls the point at which the controller starts by setting an activation flag high. It also stops the controller by setting the activation flag low.

(ii) Deactivation logic 46 which detects the necessary conditions for deactivation of the controller. When the required conditions are met, it sends a signal to the activation logic 44.

(iii) Fade Control 48 which produces a gain value between 0 and 1 that is used to fade the inputs and outputs from the controller in and out as the controller is

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switched on and off. The purpose of this is to effect bumpless transfer from controller off to controller on and back to controller off. At no time should the controller produce sudden changes in the steering torque other than those intended for the correction of oversteer.

(i) Activation Logic

The activation logic 44 merely comprises a threshold oversteer value and an SR latch 50 as shown in Fig. 8. When the oversteer signal exceeds the threshold, the latch 50 is set, and remains set until the deactivation flag triggers a reset.

(ii) Deactivation Logic

As indicated in Fig. 9, two conditions must be satisfied before the deactivation flag goes high. They are:

1. Oversteer flag should not be set. If the oversteer signal is higher than the threshold that causes activation of the controller, then the controller should not be reset.

2. Yaw acceleration should be less than a threshold. A high yaw acceleration means that there is a large yaw moment present on the vehicle, which is possibly unstable. Therefore, the yaw acceleration must fall below a threshold before the activation flag can be reset.

(iii) Fade Control

As illustrated in Fig.10, the fade control block produces a gain between 0 and 1 that fades the control effort generated by the steering controller in and out in a smooth manner. When the activation flag is high, the output from the fade out

gain is zero and the input to an integrator 52 is the value of the fade in gain. As

the fade in gain is positive, the integrator 52 ramps up to 1 where it is saturated

which allows the torque generated by the steering controller to be gradually added

to the steering system. When the activation flag falls to zero, the output from the

fade in gain falls to zero, the input to the integrator 52 is now the value of the fade

out gain. As the fade in gain is negative, the integrator ramps down to zero where

it saturates, gradually removing the effect of the controller torque from the

steering system.

The rate at which the torque is faded, can be adjusted by selection of the

fade in and fade out gains.

The aforegoing system is capable of achieving a number of advantageous

operating characteristics, including one or more of the following:

(1) Hands off stability is obtained in that the vehicle is stable even if the

driver removes their hands from the steering wheel. The steering automatically

attains the correct steer angle.

(2) Vehicle stability is enhanced in that, for a vehicle fitted with VSC, both

the steering and braking are acting to stabilise the vehicle, so that the vehicle

should be returned to a safe operating region more rapidly.

(3) Less VSC (Vehicle Stability Control) intervention is necessary.

The VSC causes the vehicle to slow down. By arranging for the steering

control to activate ahead of the VSC system, there will be less VSC action. The

VSC could also be tuned to allow more oversteer as the steering control will be

active.

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(4) The system is applicable to cheaper vehicles in that stability control can be added to a less expensive vehicle where VSC would be a prohibitive extra cost but where power steering is standard.

(5) Smooth intervention is achieved in that the controller torque is progressively added to the power assist torque so that the control intervention is not objectionable to the driver.

(6) The degree of intervention can be tunable in that by tuning of the control gains and saturation elements, the type of control can be varied from one that guides the driver into making the correct steering input to a full interventionist system where the driver can not override the steering.

(7) There is minimal additional hardware necessary in that there are minimal additional hardware requirements beyond the base vehicle. Two cheap lateral acceleration sensors may be all that is required, if VSC is not actually fitted to the vehicle.